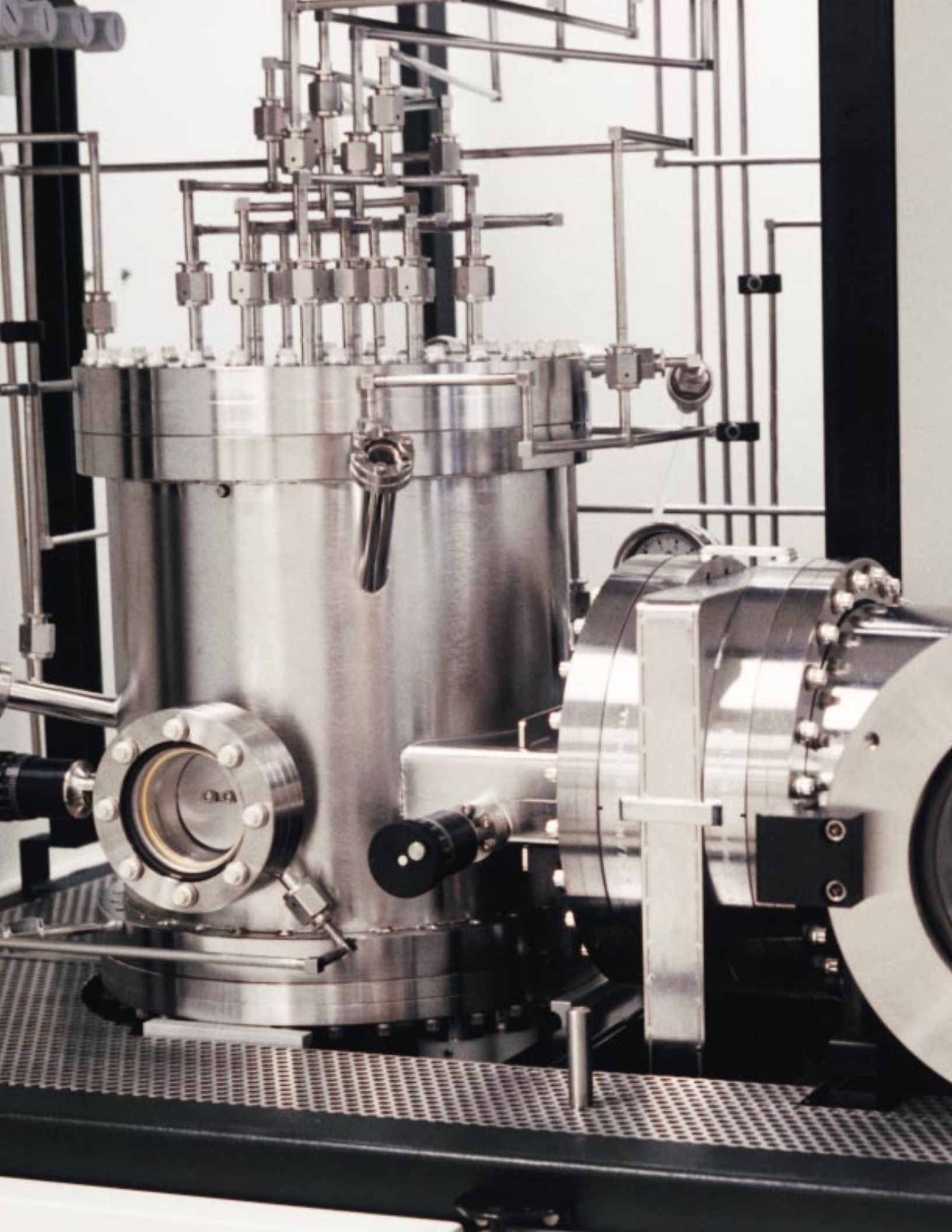
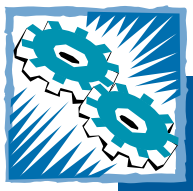


MANUFACTURING TECHNOLOGIES

Think of BMDO technology transfer the next time you

- Choose the micro-processor speed of your new computer.
- Open a bottle of aspirin.
- Purchase an electronic pager or mobile phone.
- Hear the roar of a jet engine when an airplane takes off.



WAFER MAKER PUSHES THE SPEED LIMIT

A low-cost, high-speed tool enables large-scale production of compound semiconductor-based devices for photonic and electronic applications.

■ EMCORE has developed a high-volume nitride deposition tool that combines multiwafer capabilities and patented TurboDisc™ metal-organic chemical vapor deposition technology (pictured above).

Compound semiconductor materials are attractive for new electronic devices because, unlike silicon, they can be tailored for optical and high-frequency applications. Typically, electronics manufacturers have met the needs of research and pilot production of compound semiconductor layers with in-house systems and technologies. However, producing commercial volumes of starting material often exceeds the capabilities of in-house solutions.

EMCORE Corporation (Somerset, NJ) has developed a process technology called TurboDisc™ that is key to the low-cost, high-volume production of compound semiconductors. This technology not only ensures uniformity of deposition across the wafer to produce better yields, it also allows users to scale easily from research to commercial volumes with substantially reduced time and effort. TurboDisc tools can prepare compound semiconductor wafers from 2 inches to 14 inches in diameter in a variety of material combinations.

EMCORE's technology uses a unique high-speed rotating disk in a stainless-steel growth chamber to decompose reactive gases and deposit ultrathin layers of materials (metals, conductors, oxides) on a substrate wafer. Layers grown by TurboDisc deposition allow for the design of circuits and devices that are faster and denser, have photonic capabilities, and possess properties superior to those manufactured using traditional techniques. BMDO's SBIR program funded early work at EMCORE to optimize the TurboDisc system for gallium arsenide film growth and subsequently funded EMCORE's initial research in large area growth of compound semiconductors, most notably gallium nitride.

Low-cost volume production. TurboDisc makes possible cost-effective metal-organic chemical vapor deposition (MOCVD) production systems for producing commercial volumes of high-performance compound semiconductor wafers and devices. "This technology addresses the critical need of electronics manufacturers to cost-effectively get to the market faster with higher volumes of new and improved high-performance products," says Dr. Ian Ferguson, EMCORE's director of contract research. "It's an important breakthrough that transitions MOCVD technology out of the laboratory into the production environment."

TurboDisc technology has enabled EMCORE to become the leading manufacturer of production systems used to fabricate compound semiconductor wafers.

In fiscal year 1997, a majority of the company's $47.8 million in revenues resulted from TurboDisc technology. In March of that year, EMCORE announced an initial public offering of 2.5 million shares of its common stock at $9 per share. The company raised over $20 million in proceeds, most of which will be used to expand its manufacturing facility.

TurboDisc systems are being used by some of the world's leading semiconductor companies, including Siemens, Hewlett-Packard, and Samsung. These systems come in a variety of platforms: Enterprise for volume production, Discovery for pilot production, and Explorer for research. EMCORE also offers customers the Epimetric *in situ* photoreflectance system to monitor the growth rate and thickness uniformity of a broad range of materials.

Bright blues. EMCORE's commercialization of BMDO-funded research and development has aided the development of commercial ventures in gallium nitride (GaN). The company recently introduced SpectraBlue, a TurboDisc designed specifically for the production of layers for very bright blue light-emitting diodes (LEDs) and blue lasers. In addition, it recently has entered a joint venture with the newly formed Uniroyal Optoelectronics Division of Uniroyal Technology Corporation to produce high-brightness LED epitaxial wafers, lamps, and display devices. The initial focus of the venture will be on the manufacture of GaN devices.

EMCORE's expansion into wafer and package-ready device production has been spurred almost entirely by requests from customers whose wafer needs exceed their available in-house production capabilities. For example, the company has formed a strategic relationship with General Motors Corporation to develop and manufacture magnetoresistive sensor products for use in automotive applications. It has also been involved in the development of solar cell technologies for telecommunications satellites and transmitter and display technologies for wireless communications applications.

The support EMCORE received under the BMDO SBIR program has helped motivate the company to achieve landmark results, which have recently been acknowledged by the U.S. Small Business Administration (SBA) and New Jersey Technology Council (NJTC). This year, the SBA presented EMCORE with its Tibbetts Award for superior SBIR technological innovation, economic impact, and business achievements. NJTC selected EMCORE as its Product Development Company of the Year for 1998.

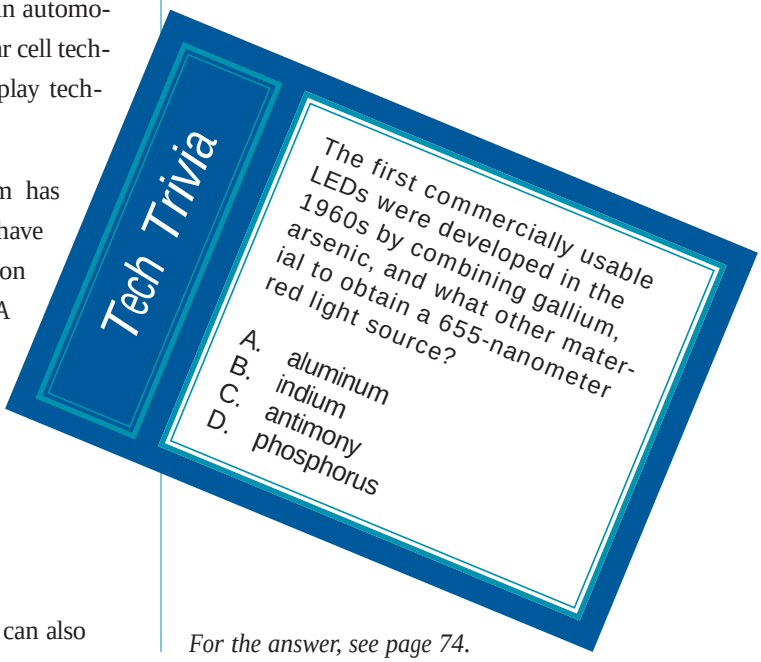
■ For more information, contact Dr. Ian Ferguson via telephone at (732) 271-9090, ext. 4114, or via E-mail at ianf@emcore.com. You can also visit EMCORE's Web site at http://www.emcore.com.

What Does It Mean to You?

Because TurboDisc systems can reduce manufacturing costs and increase production rates for compound semiconductor devices, they will allow more affordable cellular telephones, pagers, flat-panel displays, and electronic automotive components.

What Does It Mean to Our Nation?

TurboDisc systems are helping U.S. electronics and optoelectronics manufacturers, such as AT&T, Honeywell, and Uniroyal, to cost-effectively get to market faster with high volumes of new and improved high-performance products.



For the answer, see page 74.

TUNABLE FILTER SOLVES PROCESS PROBLEMS

Acousto-optic tunable filters create near-infrared instrumentation that speeds up real-time process control and analysis for a broad range of industries.

■ A near-infrared spectrometer developed at Brimrose ensures that the right pills and powders (pictured above) are in the right vials for the pharmaceutical industry.

Near-infrared (NIR) spectroscopy is ideal for keeping industry under control. NIR spectrometers will allow manufacturers to analyze industrial process problems. But mechanical-based versions have speed and reliability limitations that greatly reduce their effectiveness and survivability on the production line.

Brimrose Corporation of America (Baltimore, MD) has developed acousto-optic tunable filter (AOTF) technology that makes NIR spectroscopy a faster, more reliable tool for monitoring industrial processes. The company's all solid-state tunable filters eliminate the need for moving parts, such as rotating gratings and mirrors, to scan the NIR spectrum. This improvement not only enhances the system's reliability, but also increases its speed. While grating or mirror-based systems could scan a range of interest only once per second, Brimrose's AOTF technology can scan the same area more than 30 times faster.

Ultrasonic waves. An AOTF is a compact optical device that uses ultrasonic waves to alter the index of refraction of an optical crystalline medium. The device can obtain data in the NIR with a high degree of wavelength resolution in practically real time. Also, because the AOTF technology is all solid-state, it is rugged and has a long lifetime. In addition, the system is pre-aligned so it does not require lengthy alignment upon replacement. BMDO originally funded Brimrose's research in acousto-optics for use in optical communications, optical computers, and guidance and surveillance systems.

AOTF technology is key to successful NIR spectroscopy. "The slow data acquisition of traditional NIR instruments has been a major drawback to their commercial use in real time, closed-loop monitoring and control of industrial processes," says Dr. Gabriel Levin, Brimrose's director of applications development. "However, being able to quickly tune from one wavelength to another, AOTF technology provides rapid results. Combined with inexpensive microprocessors and powerful software, it can greatly benefit production-line technology."

Brimrose's AOTFs, which are able to analyze roughly 25 pills per second while the pills are on the conveyor belt, can be used for quality control in the pharmaceutical industry. In this way, manufacturers can ensure that the correct pills are going into the correct vials. Processing improvements are expected to increase the AOTF's capability to 100 pills per second. In either case, the sys-

tem's performance compares well to other spectrometers, which at best can read two tablets per second. In a slightly different application in the same industry, AOTFs can be used to ensure that mixtures of pharmaceutical powders are blended uniformly and that solvents are recovered efficiently.

AOTF technology also can be used to monitor the properties of petrochemicals to ensure their quality. For example, it can be used to monitor kerosene's flashpoint, which is the temperature at which kerosene can self-ignite and is related to the chemical features of the substance. It is used to automatically control the proper blending of gasoline mixtures to create the desired octane number. AOTFs have also been used to verify the proper mix of bleach for a bleach manufacturer, allowing the manufacturer to optimize the amount of water that can be used, thereby realizing savings in chemical costs. The manufacturer had previously used too much chemical intentionally to ensure that the bleach would meet minimum specifications.

The AOTF holds promise for many other production-line applications. It may be used on an assembly line to ensure quality production of ceramic cores for turbine blades. It also can help monitor the casting of large aluminum parts for automobiles. For consumer products, the AOTF has monitored the thickness of plastic film as the film is running on the rollers and has detected lack of uniformity in the material. In food applications, it has monitored the moisture content of herbs and spices before final grinding and checked orange juice quality. And in dairy plants, the spectrometer has been used to control production of butter, buttermilk, cream, and processed cheese.

Pill inspection. Brimrose has found widespread commercial success marketing its technology to the pharmaceutical industry. The company has sold more than 60 systems in this area. These systems are being used by some of the world's leading pharmaceutical companies, including Pfizer, Merck & Company, SmithKline Beecham, Hoffmann-La Roche, Ortho-McNeil, and Eli Lily and Company. In some cases, the systems are used for quality control in solvent recovery and bulk powder inspection. They are also used for powder blending and tablet inspection.

The company is making its presence known overseas as well. It has four wholly owned subsidiaries in Brazil, Israel, the United Kingdom, and Germany. An additional company is planned for 1999 in Israel. Brimrose also works through distributors in the international arena, such as in Scandinavia, Korea, and Japan.

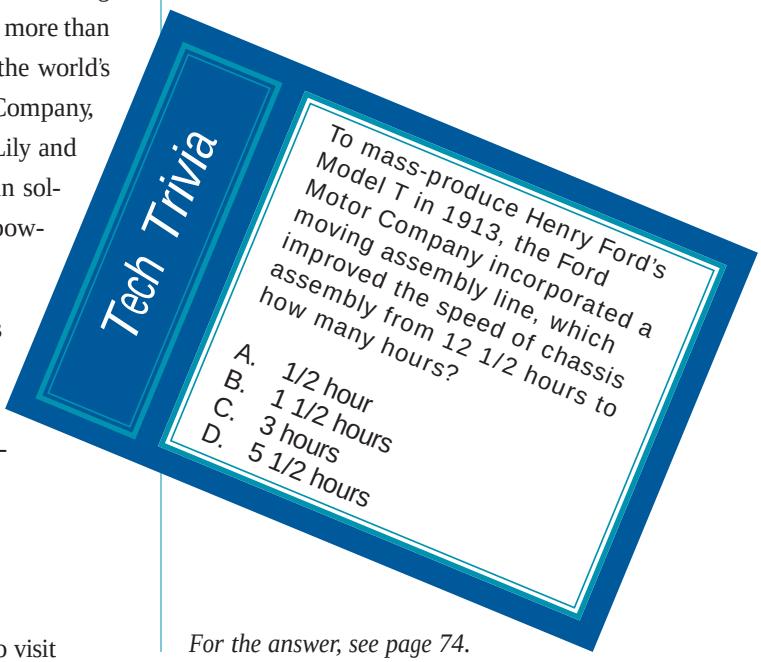
■ For more information, contact Dr. Gabriel Levin via telephone at (410) 931-7200 or via E-mail at glevin@brimrose.com. You can also visit Brimrose's Web site at http://www.brimrose.com.

What Does It Mean to You?

Acousto-optic tunable filters will help monitor industrial processes more accurately, ensuring that pharmaceuticals are properly bottled and labels on edible products are more readable and accurate.

What Does It Mean to Our Nation?

Systems based on acousto-optic tunable filter technology will help U.S. manufacturers speed up processes, thus reducing production time while increasing quality control.



For the answer, see page 74.

NEW MACHINE SHAPES UP WAFERS BETTER

A technology once used to shape optical surfaces now produces flatter, cleaner, and smoother bulk silicon and silicon-on-insulator wafers.

■ The Precision Wafer Shaper 200 (pictured above), developed by IPEC Precision, uses plasma-assisted chemical etching to produce ultraflat silicon wafers up to 300 millimeters in diameter.

For microchips to continue getting faster and more powerful, chip designers will need to make transistors smaller and the connecting lines between them thinner. A key lies in finer methods of imaging the circuitry on silicon wafers, a process known as lithography. Current lithographic techniques will be unable to provide the precise imaging needed for future chips, in part because silicon wafers aren't flat enough.

To better prepare for chip fabrication, manufacturers typically use grinding, etching, or polishing processes to smooth out the surface of these wafers, thus removing any microcracks or surface roughness. Unfortunately, many of these chemical and mechanical processes are difficult to control and can result in imperfect wafers.

One solution is high-precision wafer processing equipment developed by IPEC Precision, Inc. (Bethel, CT). This equipment produces smooth, uncontaminated, and undamaged bulk silicon and silicon-on-insulator wafers, and it does it with better control than conventional grinding, chemical/mechanical polishing, and wet chemical etching techniques do. Its precise shaping capability will help solve critical depth-of-focus problems in optical lithography used to fabricate advanced devices with line widths below 0.35 microns.

Controllable material removal. At the heart of IPEC Precision's wafer shaping equipment is a novel, patented process called plasma-assisted chemical etching (PACE). In PACE, a plasma-excited reactive gas chemically combines with the surface material to generate a volatile product that is pumped away, removing silicon in highly predictable and controllable quantities. Today, IPEC Precision maintains the rights to more than 30 patents covering many aspects of PACE technology.

Originally conceived and patented by the Perkin-Elmer Corporation, PACE was licensed to Hughes Danbury Optical Systems, which eventually sold the technology and its Precision Material Operations (PMO) group to IPEC. The PMO group was renamed IPEC Precision. BMDO funding helped Perkin-Elmer refine PACE technology for shaping and polishing optical mirrors used in missile tracking systems and high-powered lasers.

"Wafers need to be perfectly flat to allow exposures to be printed for the smaller features and linewidth characteristics of next-generation semiconductors," says Dr. Peter Mumola, IPEC Precision's president. "Our wafer processing equipment creates a flatter surface, which increases the precision with which photolithography can imprint multiple layers of circuit diagrams and reduces wafer defects in the production of advanced semiconductors. This technology opens up the possibility of pushing optical lithography well into the 21st century."

Clearly, PACE technology has made a financial difference in the company's bottom line. "In fiscal year 1997, sales of wafer processing equipment using PACE technology reached $11 million," says Randy Young, IPEC Precision's marketing director. "Our goal in fiscal year 1998 was to significantly increase this figure through add-on orders from existing customers and customer base expansion." IPEC Precision's customers include virtually all of the major semiconductor manufacturers in the world who, in turn, have sold polished silicon wafers to some of the world's largest chip makers, including Intel and Motorola.

Next-generation silicon wafers. MEMC Electronic Materials, Inc. (St. Peters, MO), recently purchased $5.4 million of IPEC Precision's machines and may buy additional tools for its worldwide semiconductor manufacturing operations. The companies agreed to implement a multiphase, two-year program to develop new tools based on PACE technology for producing future generations of silicon wafers. When the product development is complete, it is anticipated that next-generation silicon wafers will be flatter, cleaner, and smoother than any available today, and will permit MEMC's customers to produce faster, more complex semiconductor devices.

To cement the deal, IPEC and MEMC formed PlasmaSil, a limited liability company owned 60 percent by MEMC and 40 percent by IPEC Precision. PlasmaSil will own all the intellectual property developed under the cooperative development program. The goal of the company will be to license the newly developed technology to IPEC Precision and receive royalties on sales.

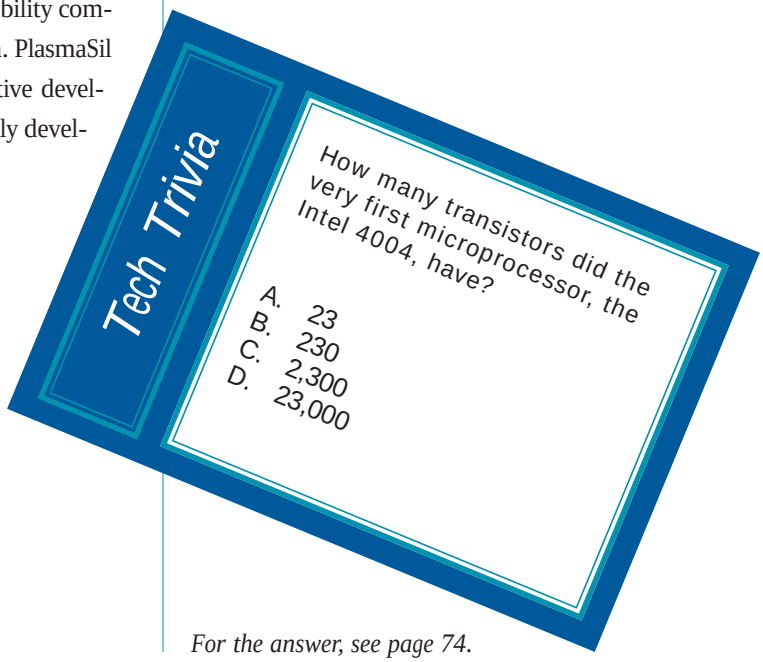
■ For more information, contact Randy Young via telephone at (203) 731-6700 or via E-mail at ryoung@ipec-precision.com. You can also visit IPEC Precision's Web site at http://www.ipec.com.

What Does It Mean to You?

New processing equipment for ultraflat silicon wafers will improve the quality and lower the cost of microchips, which have worked their way into many consumer electronics, from pagers, video games, and cellular phones to fax machines and personal computers.

What Does It Mean to Our Nation?

With major wafer suppliers using better wafer shaping equipment, chip makers such as Intel and Motorola can improve the quality of their products while reducing manufacturing costs.



For the answer, see page 74.

HIGH-ENERGY LASER BLASTS METALS

A high-energy laser system shocks metal components such as hip implants and engine fan blades, making the parts more resistant to fatigue and corrosion.

■ Lawrence Livermore technicians align the neodymium-doped glass laser (pictured above), which offers a peak power of 3 billion watts, roughly equivalent to the power output of a nuclear power plant.

Imagine using a shotgun to shoot tiny balls—as small as grains of salt—at the surface of a metal, generating a compressive stress near the surface. In essence, that is what manufacturers call peening, and they have been doing it for years to reduce metal fatigue and corrosion. In the 1980s, researchers discovered that lasers could peen metals with deeper penetration, increasing their resistance to failure in high-surface tension applications. But creating a commercially viable, high-energy, high-repetition-rate laser to accomplish this task has been difficult.

Lawrence Livermore National Laboratory (LLNL; Livermore, CA) has developed a powerful, fast-firing laser that could help bring this peening technology to market. The neodymium-doped glass laser features an average 600 watts of power and can fire 10 pulses per second. Previously, lasers for peening could generate only one pulse every two seconds, making the process economically unattractive. While conventional peening reaches a depth of about 1/100 of an inch to instill compressive stress, LLNL's laser can penetrate four times deeper. This increase is critical to stop stress-cracking in engine blades, rotors, and gears.

Laser zig-zag. The key to the laser's commercial viability is its slab cavity design, which features reduced thermal buildup and wavefront distortion to achieve higher repetition rates. Laser light propagates through the slab in a zig-zag pattern to minimize wavefront distortions. In addition, the laser's gain medium is thin, providing more efficient heat extraction. BMDO funded the development of the laser at LLNL for optical imaging of space objects. Other contributors include the U.S. Navy, the U.S. Air Force, the Department of Energy, and the Defense Advanced Research Projects Agency.

LLNL has licensed the laser peening process to, and has a cooperative research and development agreement with, the Metal Improvement Company (Paramus, NJ) to develop laser peening as a commercial process. Work under the initial phase of the agreement is expected to last about two years. Part of this effort includes working with companies to laser peen test components for their evaluation. Commercial products manufactured with the technology, called Lasershot℠ Peening, are two to four years away from introduction.

Metal Improvement, the largest U.S. supplier of peening services, says that a new laser peening system using LLNL's laser will find applications throughout

the metal working industry. "There is definitely a need for this process," says Jim Daly, Metal Improvement's senior vice president. "Laser peening won't replace conventional shot peening, but it will be used in areas where deeper depths of compressive stress are needed." In general, the "deeper the compressive stress, the better damage tolerance," adds Daly.

Strengthening airplane engine parts, such as rotors, disks, and blades, will be one of the first uses of the new laser. The U.S. Air Force sees LLNL's laser peening technology as a way to address its number one propulsion concern—high cycle blade fatigue. Early tests have shown an increase of between 10 and 40 percent in metal fatigue strength, allowing engines to operate at higher stress loads without cracking. Other aviation industry studies have shown that engine blades—which can cost $30,000 to $40,000 each—last three to five times longer when treated with the laser peening process.

Hardening parts. Laser peening has additional uses in aviation as well as other industries. The technology could be used to increase the resistance of jet engine blades to damage from objects such as birds, ice, or stones, which can damage the edge of a blade. Once an object strikes and damages the fan blade's edge, the flaw can propagate through the blade, leading to accelerated blade failure and possibly the destruction of an engine. Beyond aircraft, laser peening could be used to harden the surface of hip joint implants, making them more durable. Other potential applications exist within the automotive, oil tool, marine, chemical, and power generation industries.

The laser also could be applied to x-ray lithography, for more precise integrated-circuit etching. LLNL's laser could produce the shorter wavelengths of light needed to produce higher resolution features as fine as 0.1 microns, possibly replacing conventional optical lithography techniques. IBM is building a $700 million x-ray lithography facility using a high-power energy source called a synchrotron. If the company's technology is successful, then small producers who cannot afford a synchrotron ($100 million) could use LLNL's laser (a few million dollars).

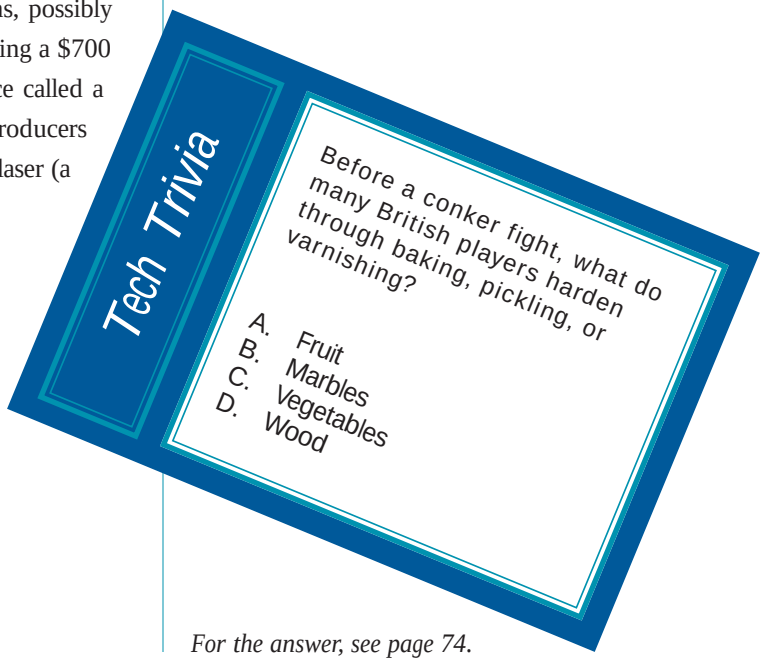
■ For more information, contact James Daly via telephone at (201) 843-7800, ext.12, or via E-mail at metalimp@ix.netcom.com. You can also visit Metal Improvement's Web site at http://www.metalimprovement.com.

What Does It Mean to You?

Laser peening means jet engine components will be made stronger and last longer, thereby making flying safer.

What Does It Mean to Our Nation?

Laser peening may create a new industry that can increase the value of manufactured metal products such as hip joint implants and jet engine blades.



For the answer, see page 74.